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RESEARCH MEMORANDUM

AERODYNAMIC LOSSES IN LOW-PRESSURE TAILPIPE EXHAUST DUCTS FOR ROCKET-PROPELLED AIRCRAFT

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

July 20, 1948

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AERODYNAMIC LOSSES IN LOW-PRESSURE TAILPIPE EXHAUST DUCTS FOR ROCKET-PROPELLED AIRCRAFT

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SUMMARY

An evaluation of the aerodynamic losses involved in the use of exhaust ducts for rocket-propelled aircraft was obtained from thrust stand tests. The aerodynamic losses created by the use of low-pressure tailpipe ducts are within practical limits insofar as over-all propulsion requirements for pilotless-aircraft models are concerned. The rocket impulse developed decreases slightly with increasing tailpipe length. For tailpipe length-diameter ratios varying from 2.5 to 7.5 the average reduction in total impulse varies from 2.9 to 5.8 percent.

INTRODUCTION

One of the primary problems in the design of aircraft, particularly those employing dynamic lift-producing surfaces, is the maintenance of the desired static and dynamic stability under the conditions of changing weight caused by expenditure of fuel or propellant. In general, static stability exists when the center of gravity of the aircraft is ahead of the neutral point.

To achieve stability that is invariant with expenditure of propellant, it is necessary to maintain the center of gravity of the propellant at the center of gravity of the aircraft. With liquid propellants or fuels this can be effected by appropriate location of the fuel or propellant tanks. In some types of aircraft, particularly certain kinds of guided missiles and jet-propelled research models, operational considerations, such as the need for simplicity in handling and launching or the need for a high thrust to weight ratio, make it highly desirable and sometimes necessary to employ solid propellant rocket motors. In these units all of the propellant is carried within the combustion chamber and the major weight of the propulsion system is located there. This gives rise to a weight-distribution problem for if the nozzle of the solid propellant rocket motor is placed at the tail of the fuselage so that the jet clears the fuselage, it is usually found that the center of gravity of the propellant is far aft of the neutral point. Ducts, termed tailpipes or blast tubes, have been devised which make possible the placing of the rocket motor so that the center of gravity of the propellant coincides with the center of gravity of the aircraft. The duct conveys the jet to the tail end of the fuselage and may be either of the high-pressure or low-pressure type. A low-pressure tailpipe is a duct attached to the nozzle exit of the rocket motor to convey gases which have been expanded to a pressure not much above atmospheric. A high-pressure tailpipe is constructed by inserting a tube between the converging and diverging sections of the nozzle, and is in effect an extension of the nozzle throat. The practicality of such ducts is dependent upon their weight, ability to withstand the heat and pressure to which they are subjected, and the magnitude of the loss of impulse which they cause. This latter is an aerodynamic problem of the flow within the duct. An experimental investigation of the effect of the variation in duct length of low-pressure tailpipes was conducted by the Langley Pilotless Aircraft Research Division for the purpose of providing design information.

Since structural considerations were not within the scope of the investigation, experimental low-pressure tailpipes with much thicker walls than are required for flight application were used in order to permit repeated testing without the possibility of structural failures. In practical applications, however, tailpipes are designed for high-pressure or low-pressure operation with various wall thicknesses, depending upon the specific design requirements involved. In general, it is desirable to design tailpipes so that their size and weight are kept at a minimum consistent with operating pressure and temperature, heat-transfer properties of the duct, and duration of gas flow.

For flight models where all available space is needed for equipment and instrumentation, the use of high-pressure tailpipes with their smaller diameters results in optimum space utilization, although there is little, if any, reduction in weight over low-pressure tailpipes because of the thicker walls required to handle the higher pressures. High-pressure tailpipes are also particularly useful for boosted model applications where they serve as strength-carrying members that aid in providing alinement of booster attachments. For long-duration rocket motors, high-pressure tailpipes, operating at nozzle-throat pressures, continuously store more heat than can be dissipated until structural failure results, so that low-pressure tailpipes are usually more practical for such applications. An investigation of high-pressure tailpipe performance is being conducted.

In general, wall thicknesses from 0.045 inch to 3/16 inch have been used for rocket motors ranging in thrust from 1000 to 5000 pounds and in outside diameter from 3.25 to 9 inches. Each application, however, requires specific design. For example, a wall thickness of 0.045 inch with stiffening rings 0.11 inch thick has proved adequate for a low-pressure tailpipe for a rocket motor rated at 1200 pounds thrust and 4 seconds duration, whereas another motor of approximately the same thrust rating for 11 seconds duration required the use of a low-pressure tailpipe 0.120 inch thick all along the wall.

DISCUSSION

Flight performance of pilotless-aircraft research models depends, for any given configuration, upon the total impulse developed by the rocket motors which propel the flight models. Total impulse I is the integral of the thrust F produced and the time duration t over which the thrust is effective:

$$I = \int F \, dt$$

For a given rocket motor, the chamber pressure developed depends upon the initial temperature of the propellant before ignition and upon the composition of the propellant. However, even among a group of motors having the same propellant and being maintained at the same temperature prior to firing, some slight inconsistencies in pressure, thrust, and duration will be exhibited due to inherent differences existing among any lot of similar rocket motors.

Thrust and duration are functions of pressure. For small changes in pressure, the resulting changes in thrust and duration tend to balance so that the total impulse I is relatively independent of small inconsistencies in burning pressure.

APPARATUS AND TESTS

The tailpipes tested were merely cylindrical ducts attached to the nozzles of 3.25-inch aircraft rocket motors. (See reference 1.) Tailpipe length-diameter ratios of 0, 2.5, 5, and 7.5 were investigated by testing rocket motors with no tailpipes, 7-inch, 14-inch, and 21-inch tailpipes, respectively. The test configurations are shown in figure 1. The tailpipes tested were strictly test models having much thicker walls than are required for flight applications.

To determine total impulse as a criterion of the effect of tailpipe ducts upon rocket-motor performance characteristics, it was necessary to obtain time histories of thrust and pressure for the several tailpipe length-diameter ratios. The rocket motors were clamped in vee blocks on the rocket thrust stand as shown in figure 2. The deflection of the thrust stand, proportional to the rocket thrust being exerted, is measured by electrical strain gages and a recording galvanometer. Timing marks are impressed on the galvanometer record by an electric timer in the system so that a complete time history of thrust is obtained. In a similar manner records showing the variation of pressure with time are obtained through the use of standard NACA pressure recorders as a check on the thrust measurements.

To eliminate variation in initial propellant temperatures among motors used in comparing tailpipe effects, the test configurations were maintained at a given temperature for sufficient time (approximately 4 hours) for temperature stabilization prior to mounting on the thrust stand.

RESULTS

The variation of thrust with time for an aircraft rocket motor with tailpipes of various length-diameter ratios is shown in figure 3 for operating temperatures of 74° F, 80° F, and 87° F. As a check on the thrust records, a similar pattern can be noted in figure 4 showing the variation of nozzle entrance pressure with time at 74° F.

No systematic variation of thrust and duration of thrust with tailpipe length can be observed. Of the three tests run at different operating temperatures (fig. 3), only that test conducted at 87° F (fig. 3(c)), shows a consistent decrease in thrust with increasing tailpipe length. These unrelated variations can be attributed to the inherent differences existing among any lot of similar rocket motors.

A comparison of results on the basis of total impulse (the integrated area under the thrust time curves), shown in figure 5, is necessary to determine the effect of tailpipe length on performance characteristics. It should be noted that, whereas the total impulse developed by the motor decreases with increasing tailpipe length, the effect is moderate. The test results show that the average reduction in total impulse is 2.9 percent for tailpipe length-diameter ratio of 2.5; 4.7 percent for L/D of 5, and 5.8 percent for L/D of 7.5. On the basis of these results, the aerodynamic losses created by the use of low pressure tailpipes are within practical limits insofar as over-all propulsion requirements for pilotless-aircraft models are concerned.

CONCLUSIONS

The aerodynamic losses created by the use of low-pressure tailpipe ducts are within practical limits insofar as over-all propulsion requirements for pilotless-aircraft models are concerned. The total impulse developed decreases with increasing tailpipe length, but the effect is small. For tailpipe length-diameter ratios varying from 2.5 to 7.5 the average reduction in total impulse varies from 2.9 to 5.8 percent.

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REFERENCE

1. Anon.: Internal and External Ballistic Data, Fin Stabilized Rockets. OSRD Rep. No. 2409, CIT, UBC 28, NDRC, Div. 3, Sec. L, March 15, 1945.

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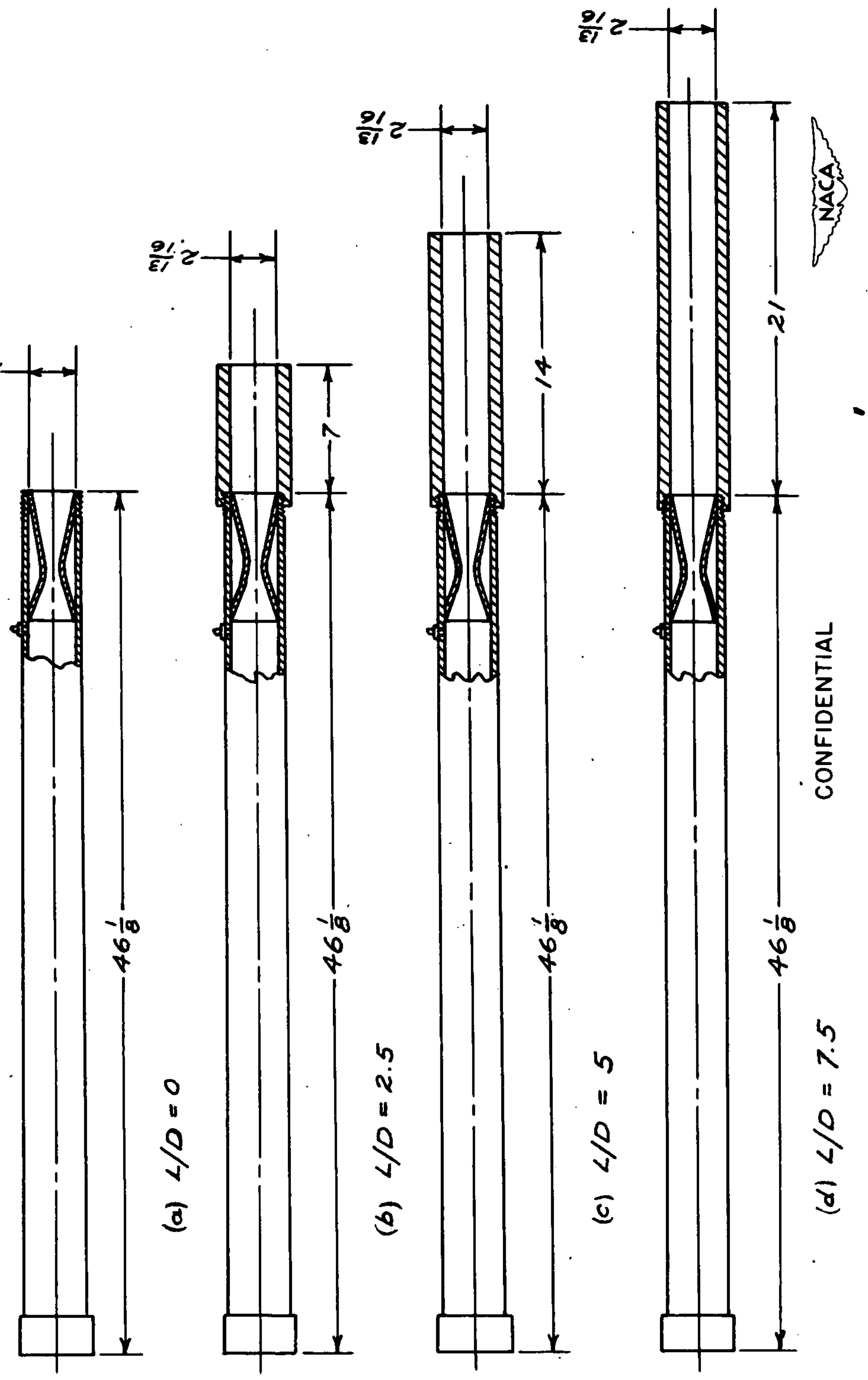

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Figure 1.- Experimental tailpipe configurations tested using 3.25-inch aircraft rocket motors.

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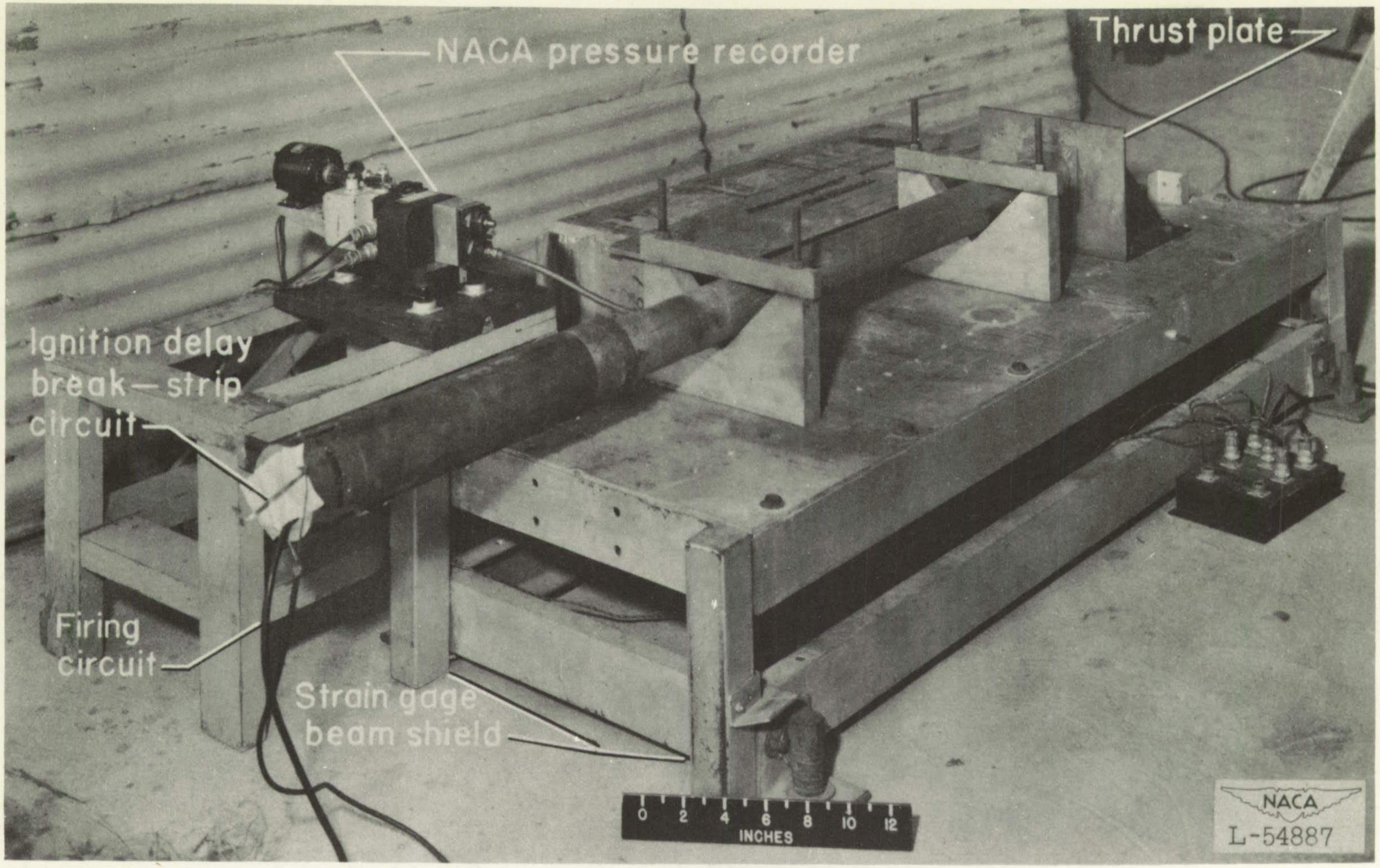

(a) 3.25-inch aircraft rocket motor with 21-inch tailpipe $\left(\frac{L}{D} = 7.5\right)$.

Figure 2.- Rocket thrust stand with test installation for measuring thrust and pressure.

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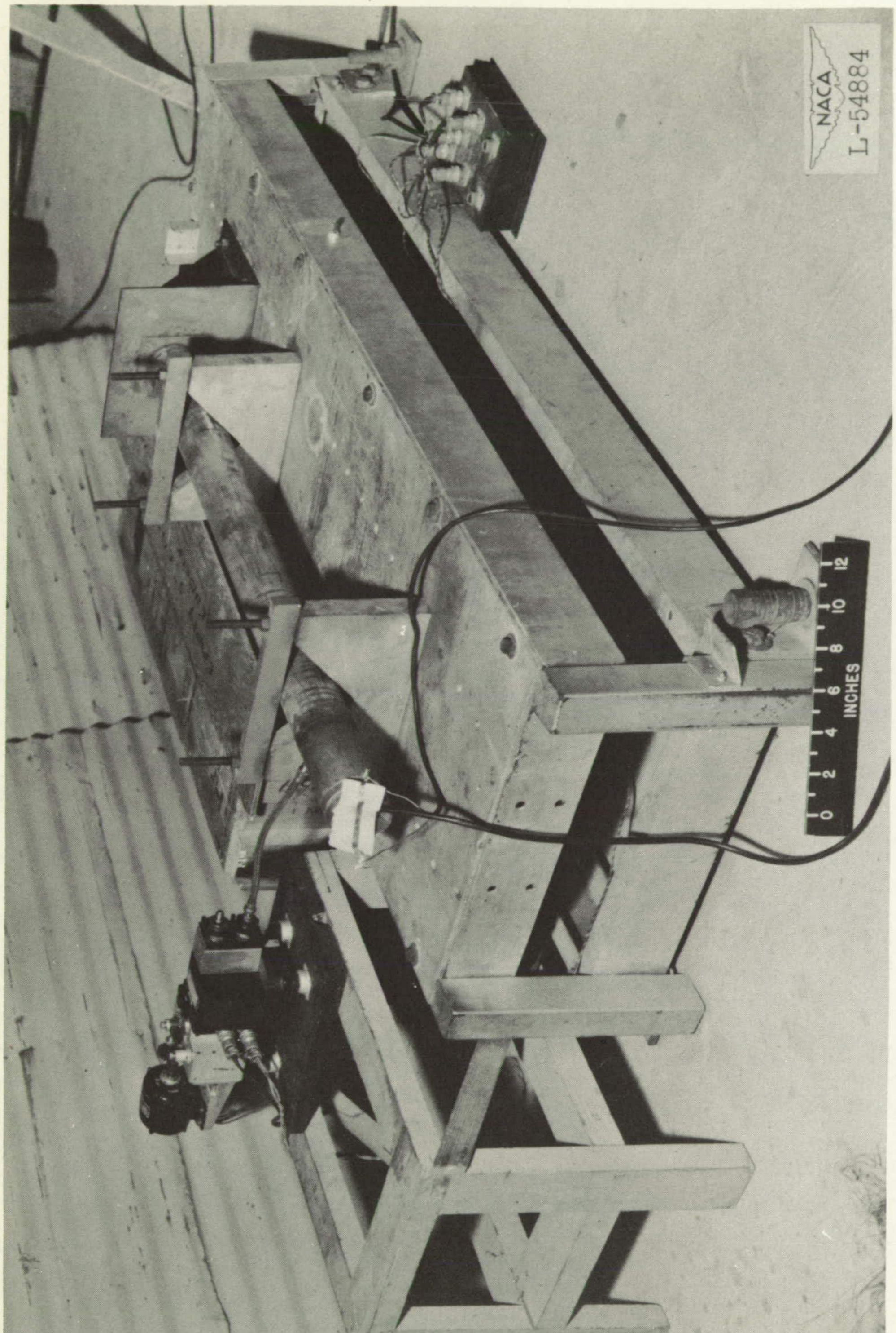

(b) 3.25-inch aircraft rocket motor with no tailpipe $\left(\frac{L}{D} = 0\right)$.

Figure 2.- Concluded.

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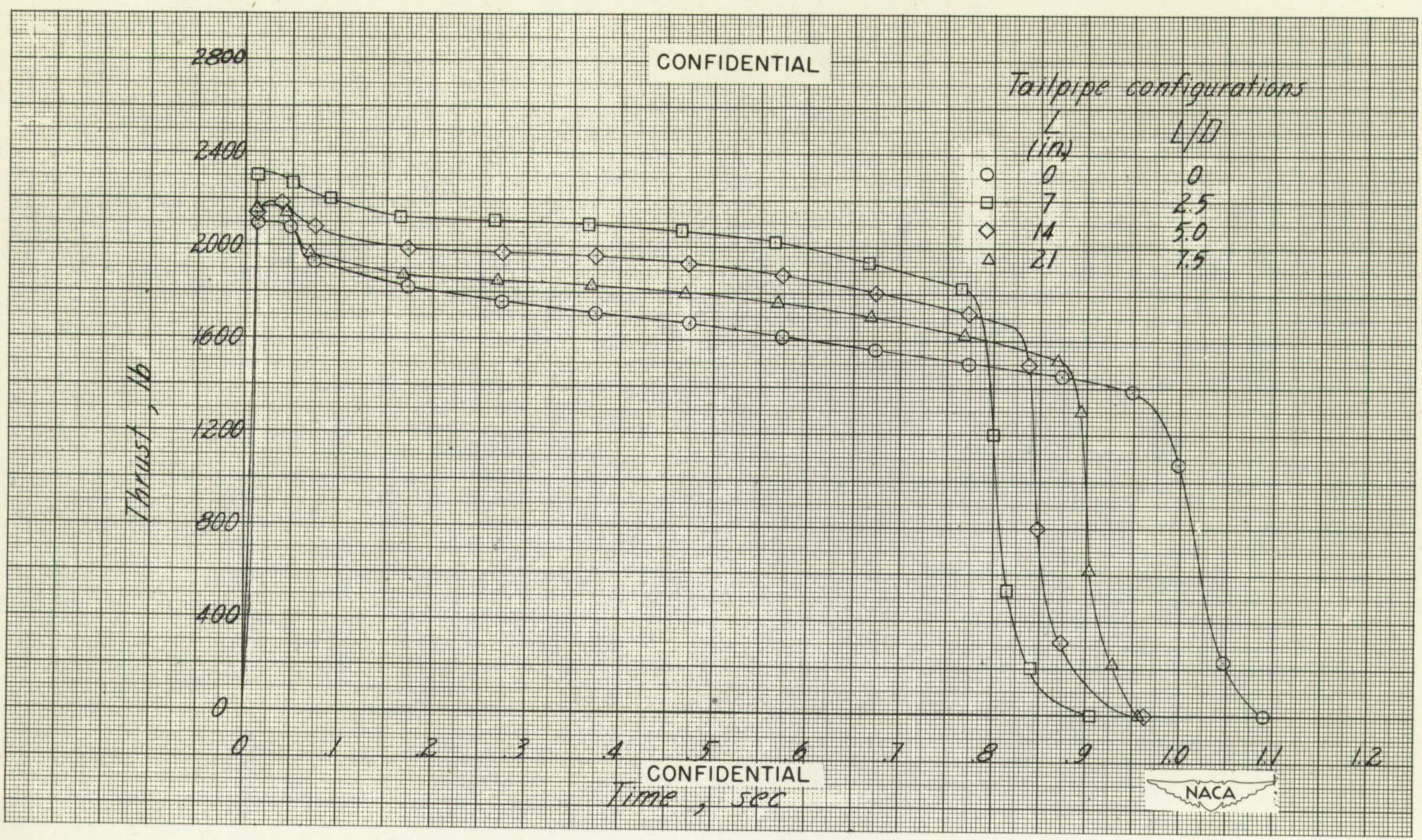
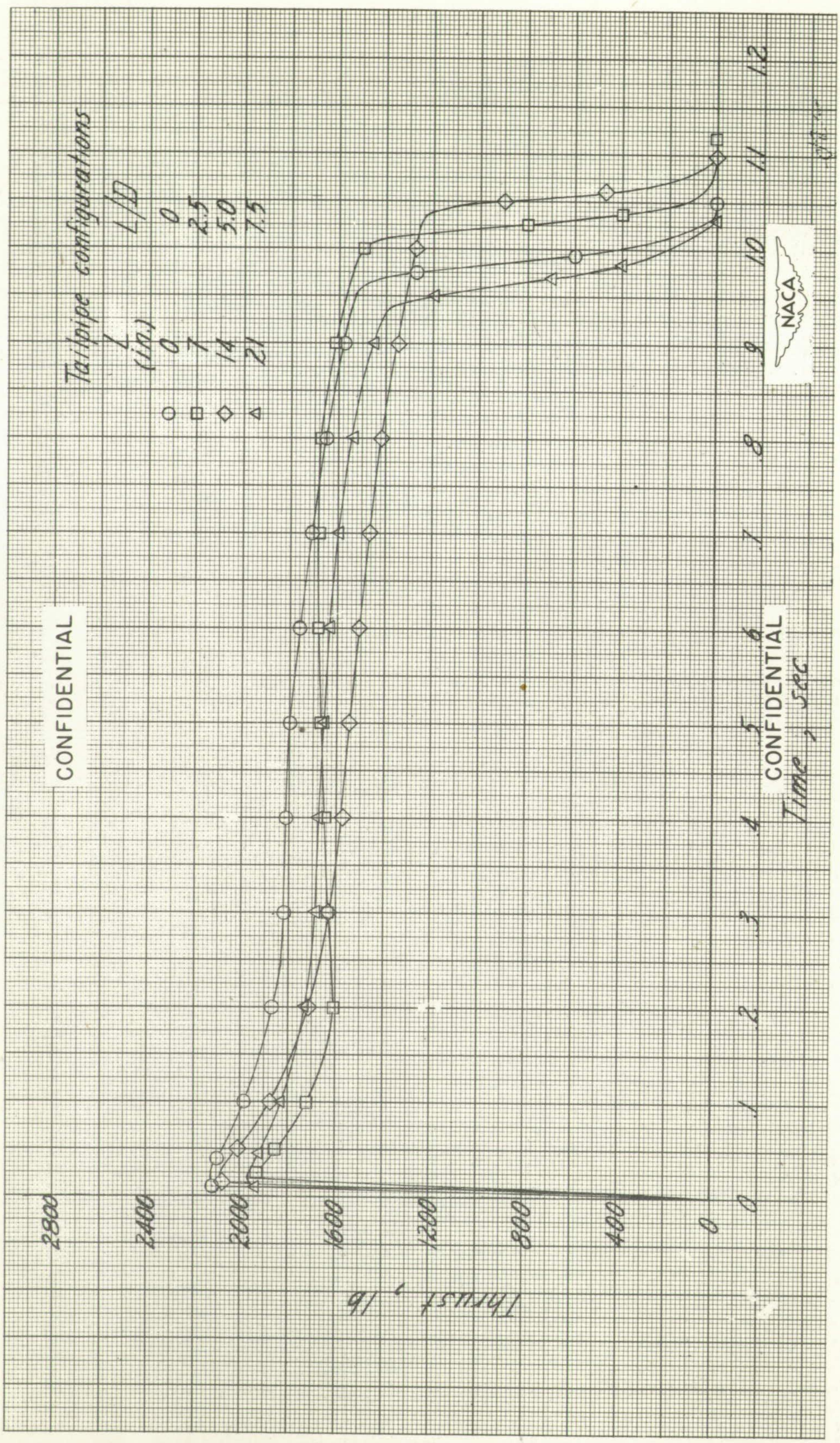


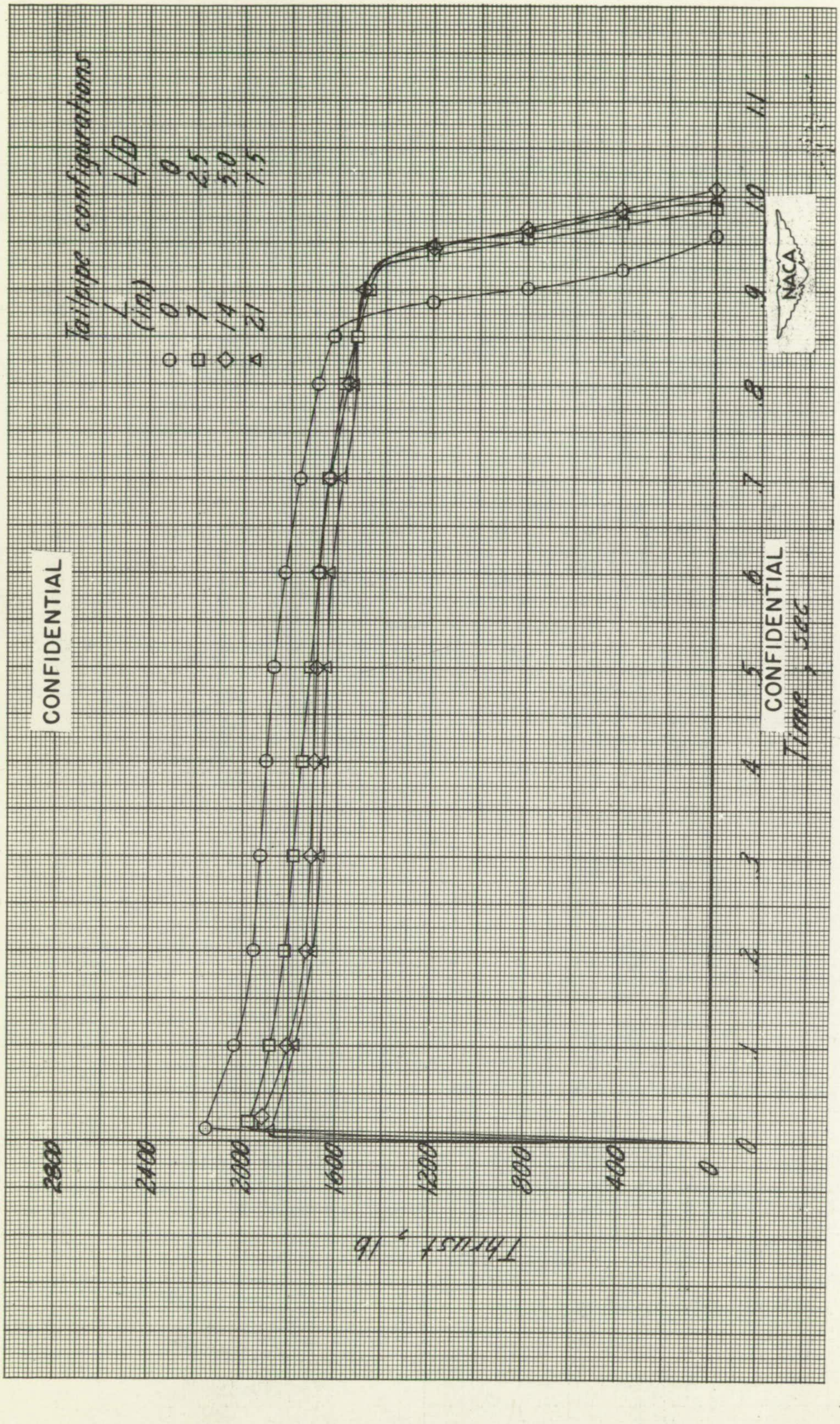
(a) Initial propellant temperature, 74° F.

Figure 3.- Variation of thrust with time for 3.25-inch aircraft rocket motors with tailpipes of various lengths.



(b) Initial propellant temperature, 80° F.

Figure 3.- Continued.



(c) Initial propellant temperature, 87° F.

Figure 3.- Concluded.

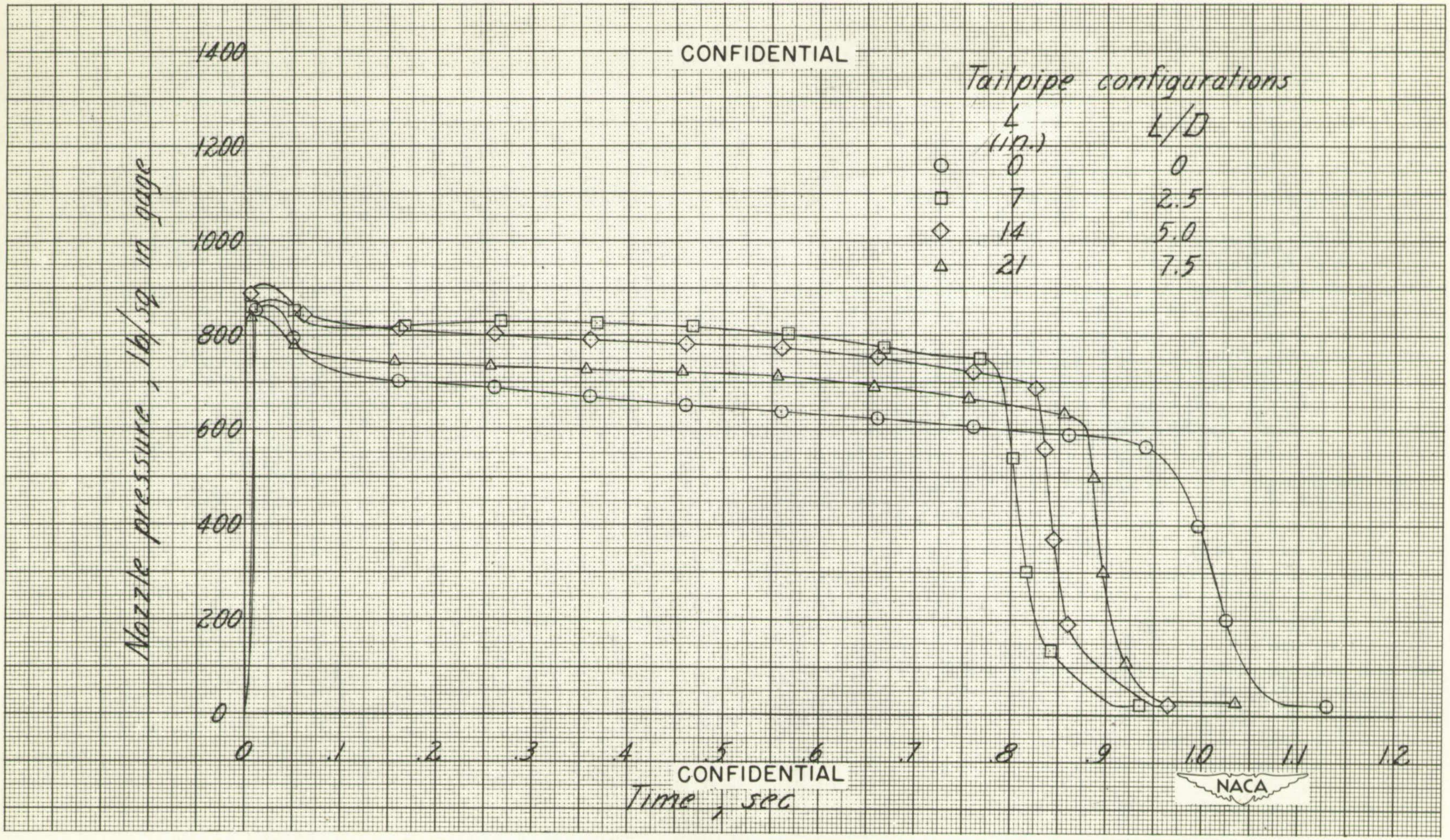


Figure 4.- Variation of nozzle entrance pressure with time for 3.25-inch aircraft rocket motors with tailpipes of various lengths. Initial propellant temperature, 74° F.

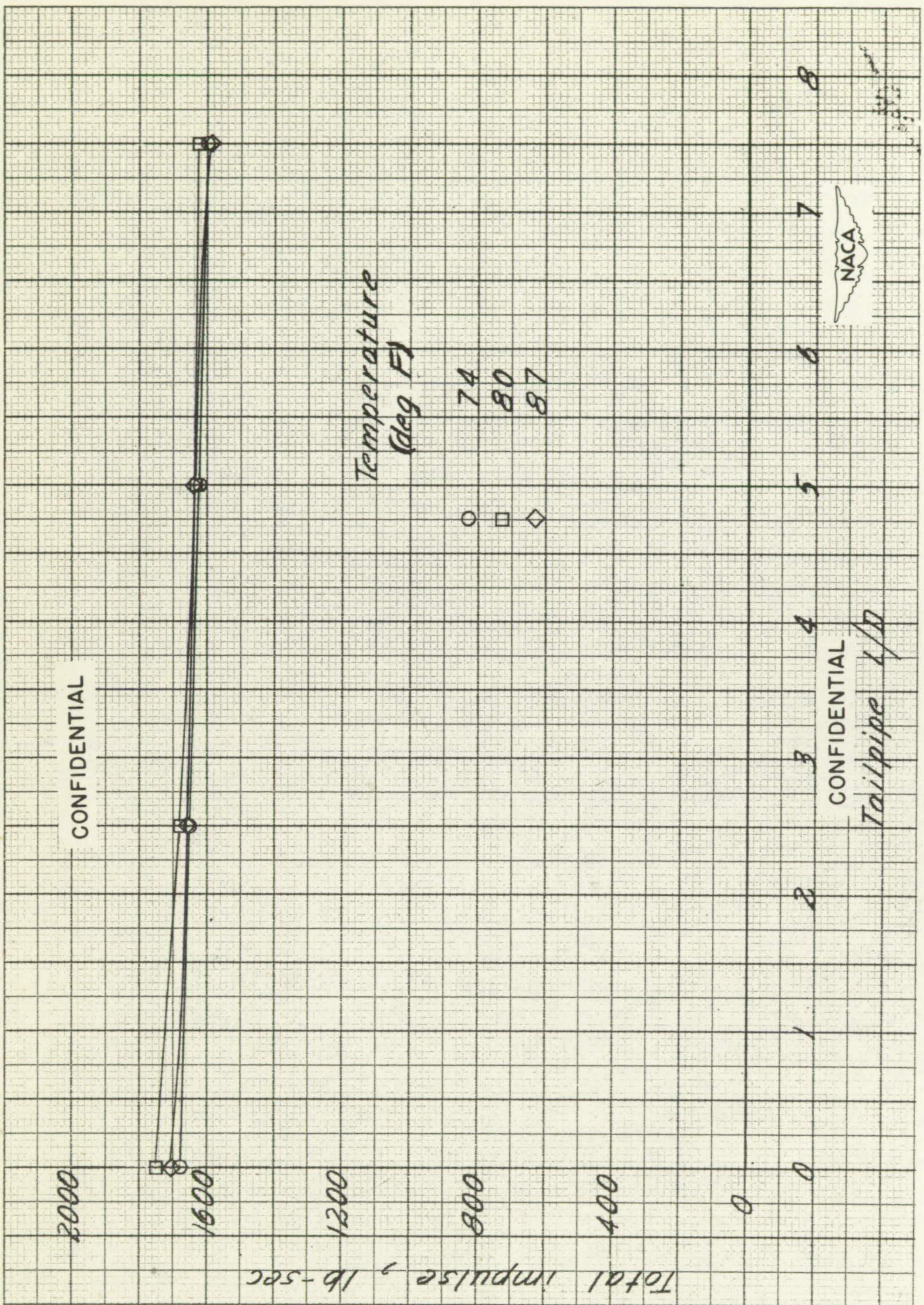


Figure 5.- Variation of total impulse with tailpipe length for various initial propellant temperatures.